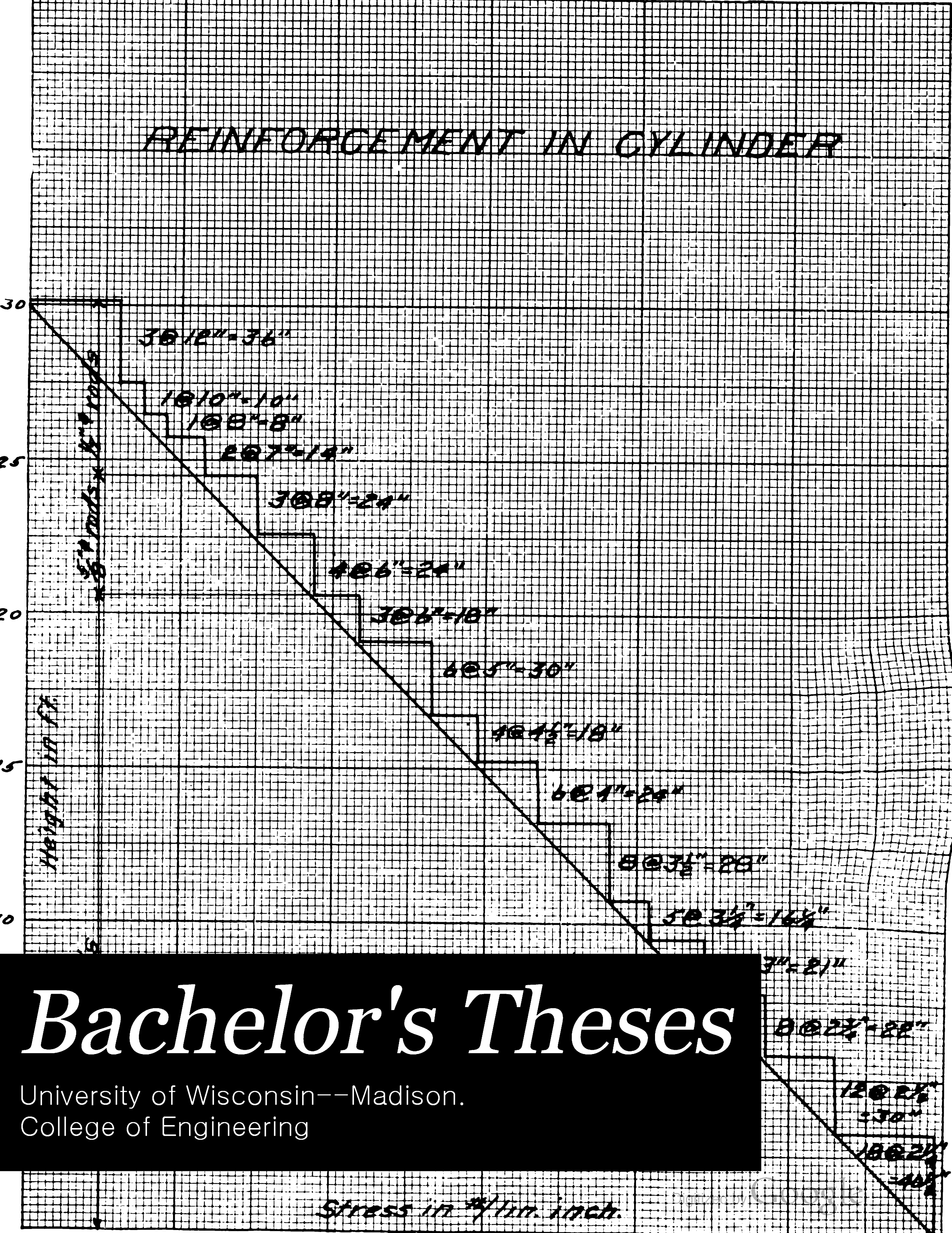

Bachelor's Theses

University of Wisconsin--Madison.
College of Engineering

THE DESIGN OF A REINFORCED CONCRETE WATER TANK

by

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A Thesis Submitted for the Degree of

BACHELOR OF SCIENCE

Civil Engineering Course

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1911

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INTRODUCTION

Reinforced concrete is now replacing steel and wood as a material of construction in many engineering structures. It is especially advantageous in tank construction because of its durability and low maintenance charge whereas steel tanks, especially for waters containing certain minerals, have been found to deteriorate very rapidly due to rusting. The concrete, however, can carry no tension, but must serve merely to protect the steel.

The writer, in submitting this design for the degree of Bachelor of Science in Civil Engineering, considered a tank of sufficient capacity for a large railroad yard where many locomotives are handled.

GENERAL DESCRIPTION

The tank is made up of a cylindrical wall 30' -0" inside diameter and 30' - 0" high, a hemispherical bottom, and a conical roof with a rise of 10' - 0". Eight columns spaced equally on a circle of 28' - 0" diameter support the structure. The capacity is 28,200 cu. ft. or 211,500 gallons.

The working stress in the steel was taken at 12,000 #/in^2. The low value was used to prevent cracks as far as possible. Concrete was assumed to carry 450 #/in^2 compression in columns, but no tension. The wind pressure was taken as 25 #/sq. ft. of the projected area. This is somewhat higher than the general rule - 40 #/sq. ft. on one half the pro-

jected area - but was used for greater safety as tanks are often on especially exposed sites. The soil was assumed to be capable of bearing safely 2 tons/sq. ft., corresponding to the American Bridge Company's loading of ordinary clay and dry sand mixed with clay.

CYLINDRICAL WALL

The forces to be considered in the design of the wall are (1) the weight of the wall; (2) the water pressure; and (3) the wind pressure.

The wall was assumed six inches thick. Tanks have been built with walls as thin as three inches and as thick as nine inches. In the former case it was extremely difficult to obtain impervious walls, and in the latter case no advantage was obtained for the extra thickness above about six inches.

<u>Weight of tank</u>

$$W = \pi \times 30.5 \times 0.5 \times 30 \times 150 = 216{,}000\#$$

$$S = \frac{W}{12\pi dt} = \frac{.026\ W}{dt} = \frac{.026 \times 216{,}000}{30.5 \times 6} = 30.6\ \#/in^2.$$ Comp. in concrete O. K.

<u>Water pressure</u>

Stress per vertical linear inch $= \frac{62.5\ h\ d}{2 \times 12} = 2.6\ h\ d$

where h = height in ft.

d = diameter in ft.

Then stress at bottom = $2.6 \times 30 \times 30 = 2340\ \#$/lin. inch tension.

Wind pressure

The cylinder acts as a cantilever.

$M = 25\ d\ h \times \frac{h}{2} = 12.5\ d\ h^2$ ft.#

$S = \frac{Mc}{I}$ where c = radius and $I = \frac{\pi t r^3}{12}$

Approximately, where t = thickness of shell in inches (See Turneaure & Russell "Public Water Supplies" - page 713)

$$S = \frac{1}{144} \times \frac{Mr}{\frac{\pi t r^3}{12}} = \frac{1.33\ h^2}{td} \#/in^2$$

$$S = \frac{1.33h^2}{d} = \text{stress per linear inch}$$

$$S = \frac{1.33 \times 900}{30.5} = 39.2\#/\text{lin. in. tension.}$$

Then total tension at bottom of cylinder = 2380#, varying uniformly to zero at the top.

Reinforcement in Cylinder

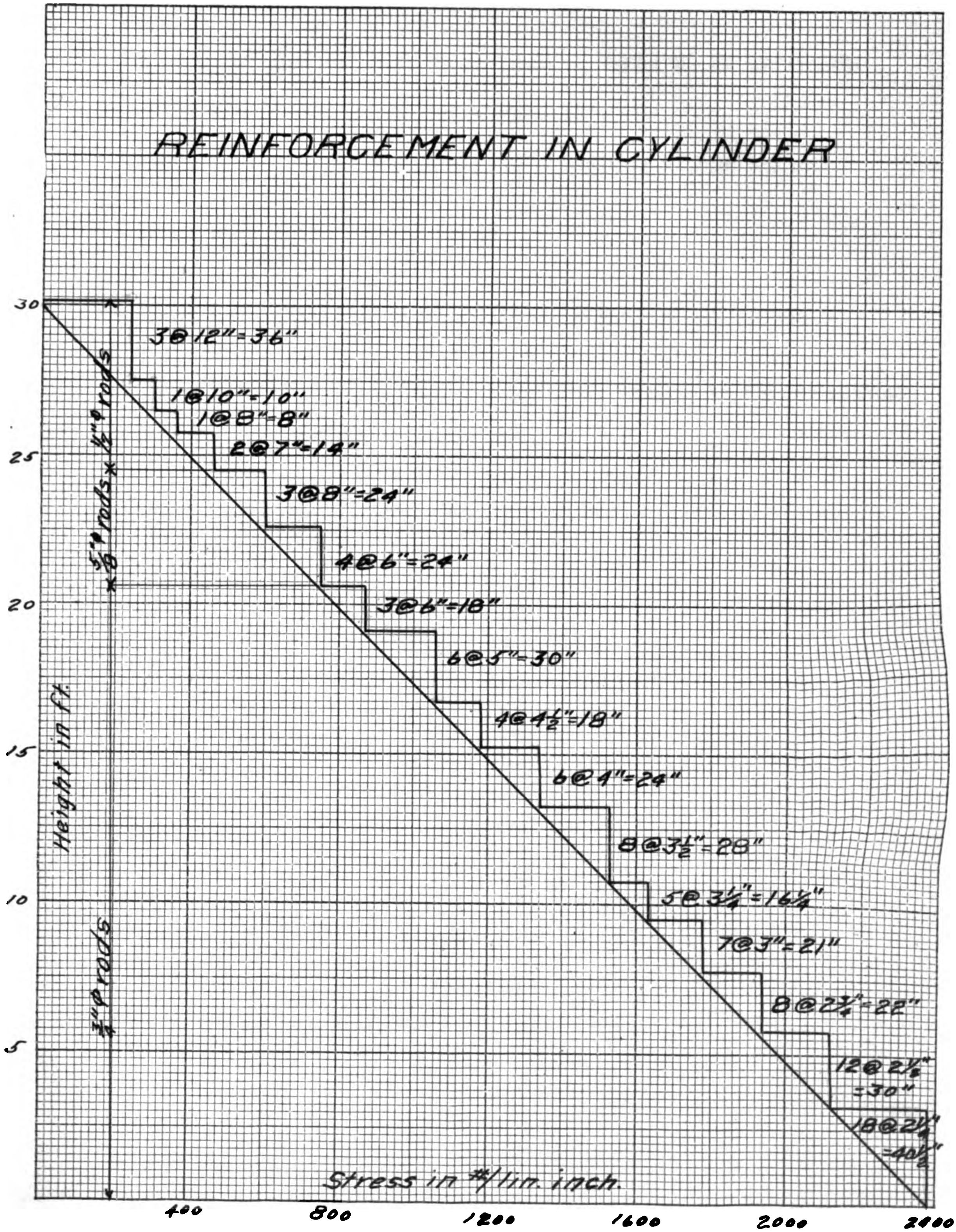
Assume 1/4" round vertical rods on 24" centers for full length of cylinder - not included in the required steel area.

$$\text{Spacing of horizontal rods} = \frac{\text{steel area} \times \text{steel stress}}{\text{total stress at any point}}$$

See figure (1) for size and spacing of horizontal rods.

HEMISPHERICAL BOTTOM

The stress in a hemisphere may be resolved into two parts, the streee on a meridian, or radical joint, and the stress on a circumferential joint. Let T_1 and T_2 equal the tension per linear inch on the two sections respectively. Then $T_1 = T_2 = 1/2\ Vr$ where V = vertical


REINFORCEMENT IN CYLINDER
30
25
20
15
10
5
400
800
1200
1600
2000
2400
Height in ft.
Stress in #/lin. inch.
3@12"=36"
1@10"=10"
1@8"=8"
2@7"=14"
3@8"=24"
4@6"=24"
3@6"=18"
6@5"=30"
4@4½"=18"
6@4"=24"
8@3½"=28"
5@3¼"=16¼"
7@3"=21"
8@2¾"=22"
12@2½"=30"
18@2¼"=40½"
⅝"φ rods
½"φ rods
¾"φ rods
Fig. 1

pressure in #/in^2 and r= radius in inches. (See M. S. Ketchum's "Walls, Bins and Grain Elevators" - page 137.

The stress varies uniformly to a maximum at the bottom.

$$V = \frac{62.5 \times 45}{144} = 19.5 \ \#/in^2$$

$$T_1 = T_2 = \frac{19.5 \times 15 \times 12}{2} = 1760 \ \#/\text{lin. in. at bottom.}$$

The circumferential reinforcement was spaced in the same manner as that for the cylinder. (See Fig. 2).

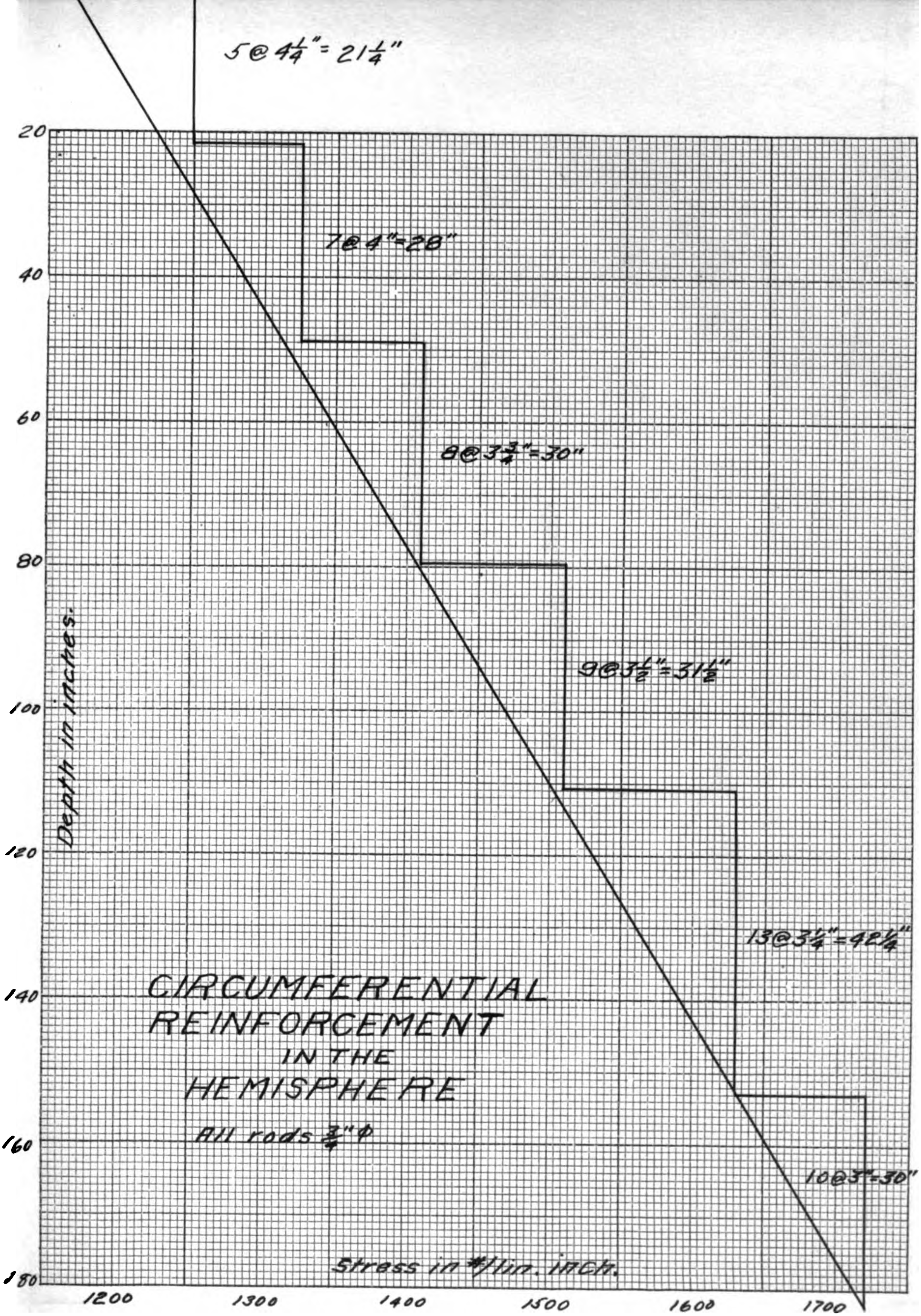
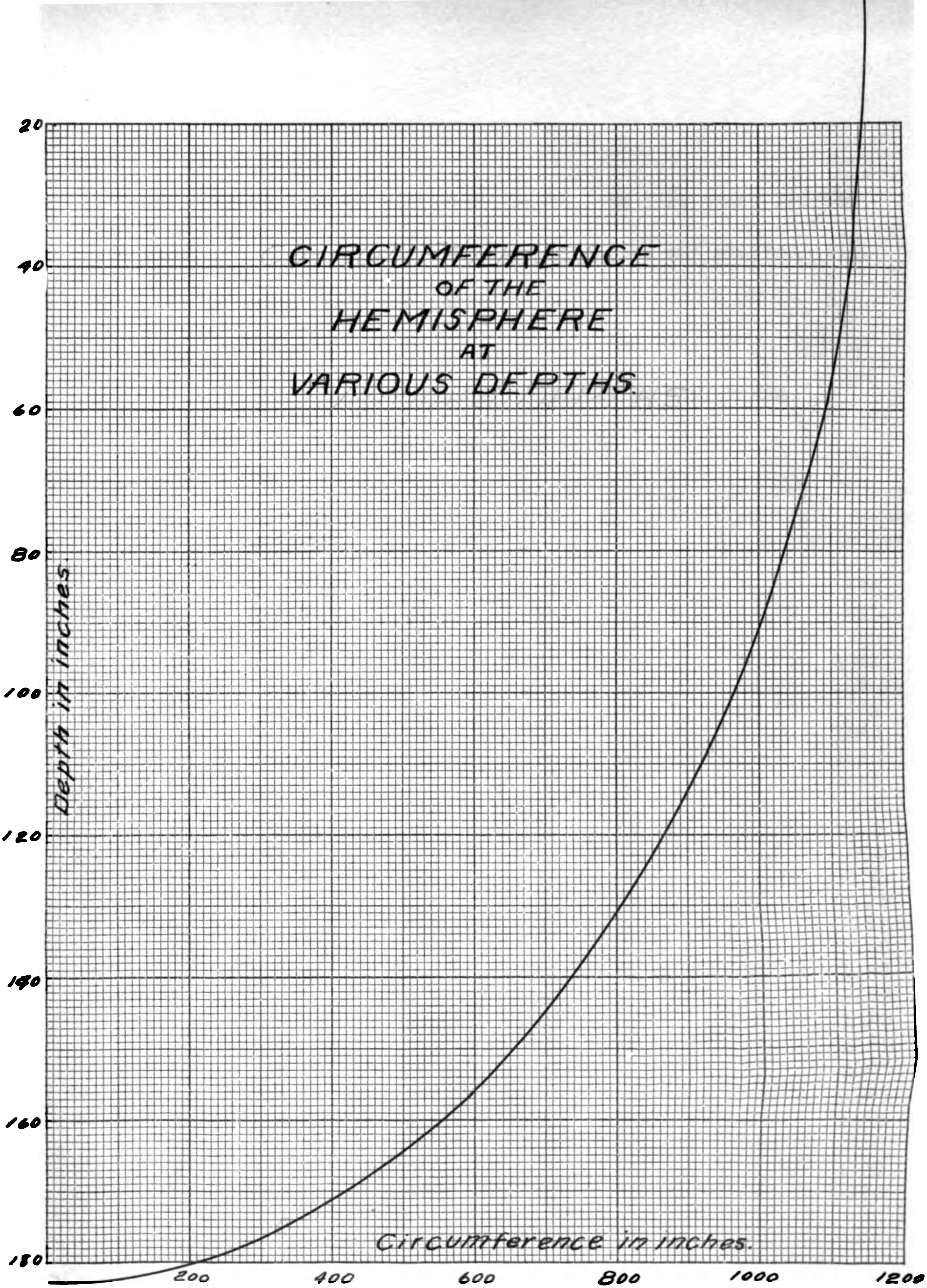

5 @ 4 1/4" = 21 1/4"
7 @ 4" = 28"
8 @ 3 3/4" = 30"
9 @ 3 1/2" = 31 1/2"
13 @ 3 1/4" = 42 1/4"
10 @ 3" = 30"
CIRCUMFERENTIAL REINFORCEMENT IN THE HEMISPHERE
All rods 3/4" φ
Depth in inches.
Stress in #/lin. inch.
20
40
60
80
100
120
140
160
180
1200
1300
1400
1500
1600
1700

Fig. 2

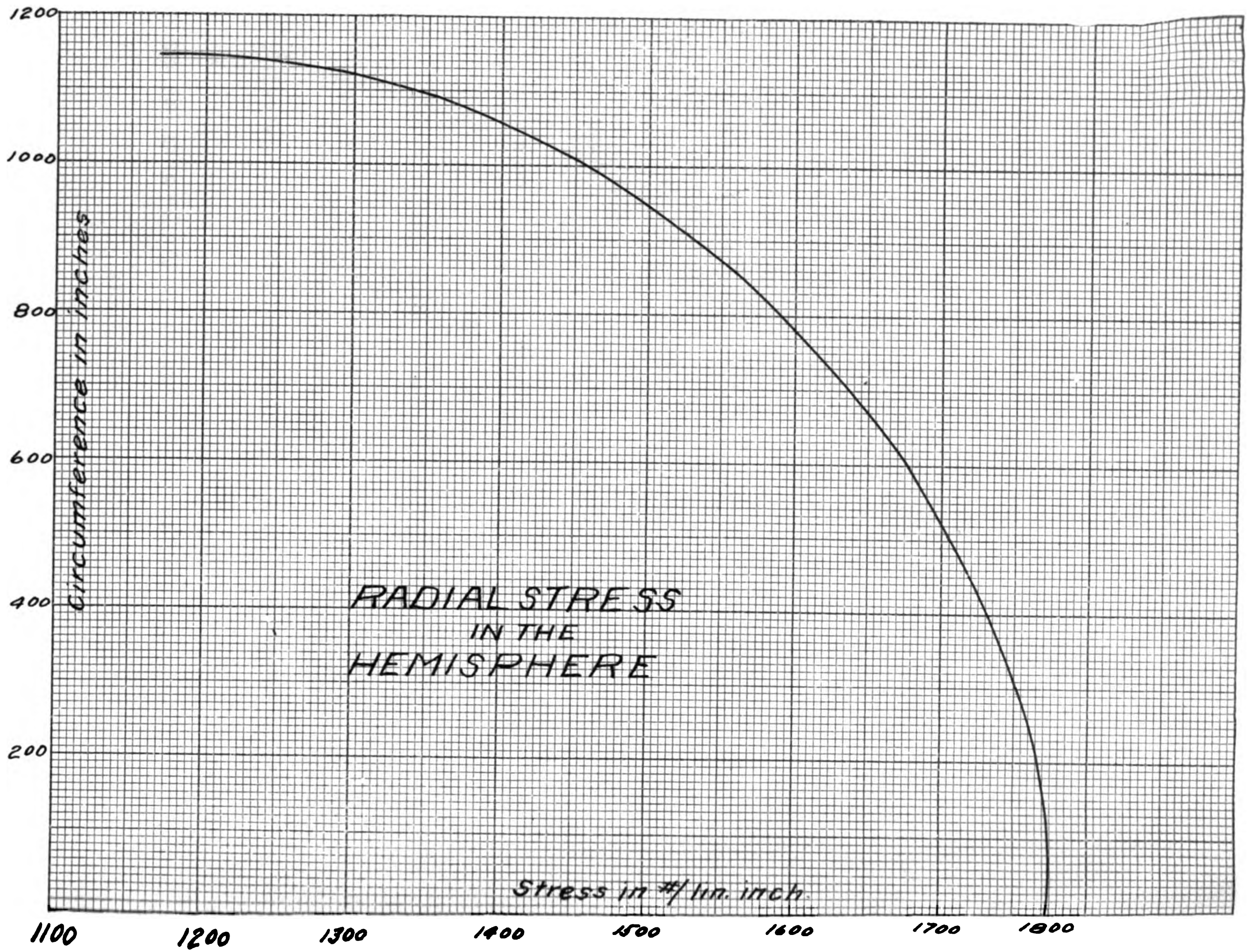

CIRCUMFERENCE
OF THE
HEMISPHERE
AT
VARIOUS DEPTHS.
Depth in inches.
Circumference in inches.
20
40
60
80
100
120
140
160
180
200
400
600
800
1000
1200

Each rod will be of different length. To find these lengths a curve showing the circumference at various depths was plotted (Fig. 3) and the following table was made:

CIRCUMFERENTIAL REINFORCEMENT OF HEMISPHERE

All rods 3/4" round

No. of rod	Spacing in inches	Distance from top in inches	Circumference in inches	No. of rod	Spacing in inches	Distance from top in inches	Circumference in ins.
1	3	181.5	150	27	3½	98.25	970
2	3	178.5	250	28	3½	94.75	985
3	3	175.5	330	29	3½	91.25	995
4	3	172.5	385	30	3½	87.75	1012
5	3	169.5	435	31	3½	84.25	1020
6	3	166.5	480	32	3½	80.75	1032
7	3	163.5	520	33	3½	77.25	1045
8	3	160.5	550	34	3½	73.5	1055
9	3	157.5	585	35	3½	69.75	1065
10	3	154.5	615	36	3½	66	1075
11	3¼	151.25	640	37	3½	62.25	1085
12	3¼	148	670	38	3½	58.5	1092
13	3¼	144.75	695	39	3½	54.75	1100
14	3¼	141.5	720	40	3½	51	1106
15	3¼	138.25	745	41	4	47	1115
16	3¼	135	770	42	4	43	1120
17	3¼	131.75	795	43	4	39	1125
18	3¼	128.5	815	44	4	35	1130
19	3¼	125.25	838	45	4	31	1135
20	3¼	122	858	46	4	27	1140
21	3¼	118.75	875	47	4	23	1144
22	3¼	115.5	895	48	4¼	19.25	1146
23	3¼	112.25	910	49	4¼	15	1148
24	3¼	108.75	930	50	4¼	10.75	1150
25	3¼	105.25	945	51	4¼	6.25	1150
26	3¼	101.75	960	52	4¼	2	1150



RADIAL STRESS
IN THE
HEMISPHERE
Circumference in inches
Stress in #/lin. inch
1200
1000
800
600
400
200
1100
1200
1300
1400
1500
1600
1700
1800

RADIAL REINFORCEMENT

A curve was plotted between stress in #/lin. inch and circumference in inches. (See Fig.4).

The number of radial rods required on any circumferential rod =

$\frac{\text{circumference x stress}}{\text{steel stress x steel area}}$ and the spacing = $\frac{\text{circumference}}{\text{req'd No. of rods.}}$

RADIAL REINFORCEMENT OF HEMISPHERE

All rods 1" round

Distance from top in inches	No. rods required	Spacing inches	Used
182	25	5.58	50 on 1 spaced 3"
181	32	5	(25 loops bent
180	38	5.275	so as to clear
179	45	5.34	each other at bottom)
178	50	5.30	On 2 add 20 70 @ 3.57"
177	54	5.36	
175	64	5.23	
170	79	5.44	On 4 add 20 90 @ 4.275"
165	91	5.5	
156	107	5.62	On 6 add 20 110 @ 4.36"
144	122	5.73	
132	135	5.9	On 10 add 20 130 @ 4.725"
120	144	6.04	
108	150	6.19	On 15 add 20 150 @ 4.96"
96	154	6.36	
84	157	6.5	On 24 add 10 160 @ 5.8"
72	157	6.75	
60	157	6.925	
48	156	7.11	
36	154	7.34	
24	152	7.51	
12	147	7.8	
0	143	8.05	On 52 - 160 @ 7.2"

Note - Numbers in last column refer to circumferential rods.

ROOF

Assume 12" projection beyond walls

Span = 30 + 1 + 2 = 33'

Assume rise = 10'

Assume snow load = 40#/sq. ft.

Assume concrete 3" thick = 36.4 " "

Assume waterproofing = 3.6 " "

Total load = 80 " " = p

Vertical force at any point = $p\pi r^2$. (See Greene's "Structural Mechanics" - page 213).

Stress per linear inch on circumferential section =

$$\frac{p\pi r^2 \sec\theta}{2\pi r^1} = \frac{pr\sec\theta}{2}$$

Stress per linear inch on radial section = $p\ r\ \sec\theta$ where θ = the angle between one side of the roof and the vertical

$$\theta = \frac{\sqrt{10^2 + 16.5^2}}{10} = 1.93$$

Maximum stress at bottom = 80 x 16.5 x 1.93 = 2550#/lin. ft.

Necessary area per linear inch 12" wide = $\frac{2550}{12000}$ = .212 sq. in.

Use expanded metal No. 25-3

Stress per linear inch to be resisted at edge of wall =

$$\frac{p\ r\ \sec\theta}{2} = \frac{80 \times 15.5 \times 12 \times 1.93}{144 \times 2} = 100\ \#/\text{lin. in.}$$

Horizontal component of this stress = $\frac{15.5}{18.5}$ x 100 = 84 #/lin.in.

Necessary steel concentrated at the top to carry this thrust =

$$\frac{31 \times 12 \times 84}{12000} = 2.6 \text{ sq. in.}$$

Use 2 - 1 3/8" round rods (See general drawing).

COLUMNS

The columns are to have no bracing, hence they must carry both the direct compressive stress and the bending stress due to the wind. The latter stress was assumed as applied at the bottom of the cylinder. From that point to the top of the cylinder the inner faces of the columns were given such a batter that at the top the thickness was the same as that of the wall. Stress from the wall was assumed to be transmitted to the columns in a manner similar to the transference of stress from a floor slab to a beam.

Loads

Roof load	$= 80 \times 1/2\,\pi\,D\,H \sec\theta$	=	80,000 #
Cylinder walls	$\pi\,D\,H \times 150 \times 1/2$	=	216,000 #
Hemisphere	$1/2\,\pi\,D^2 \times 150 \times 1/2$	=	110,000 #
Water	28,200 cu. ft. @ 62 1/2#	=	1,760,000 #
	Load on 8 columns	=	2,166,000 #

Load on each column = 271,000 #

Wind pressures

Projected sq. ft. in roof = 10 x 15.5 = 155

Projected sq. ft. in cylinder = 31 x 30 = 930

Projected sq. ft. in hemisphere $= \frac{\pi D^2}{8} = 378$

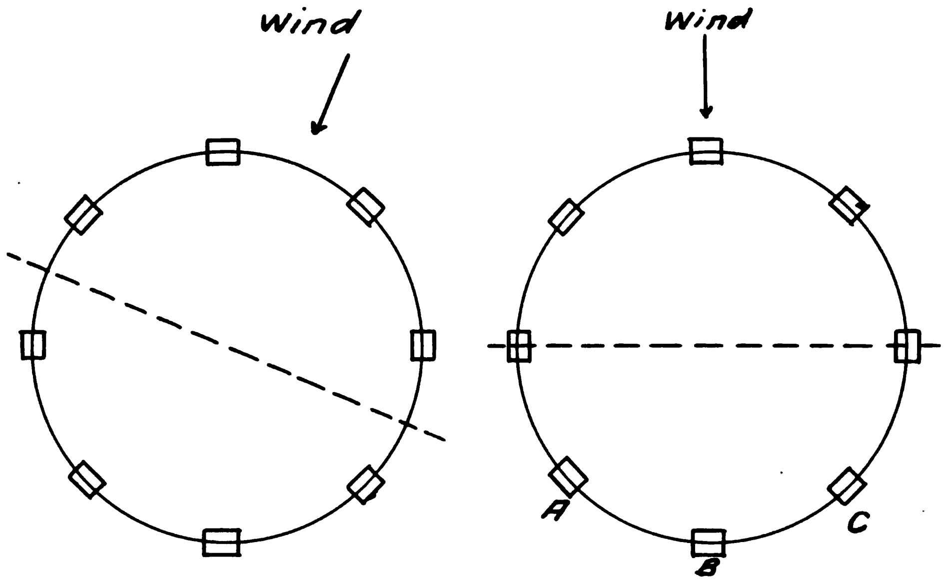
Total area = 1463 sq. ft.

Center of gravity of surface = 155 x 33 1/3 + 930 x 15

$= 378 \times \frac{4 \times 15.5}{3\pi} = 1463\ X$

X = 11.37' above bottom of cylinder.

Total wind pressure = 25 x 1463 = 36,600#



(a) (b)

(Four Posts)

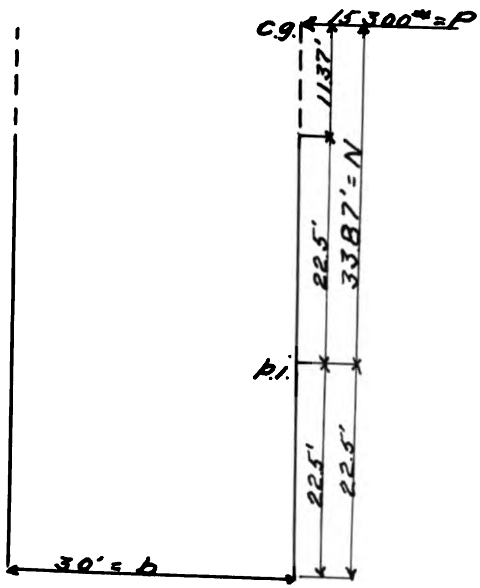
Assume wind as shown in (b).

Then stress is carried by three posts - A, B, C.

A and C will each carry less than B.

Assume A and C carry 7/24 each. Then B carries 5/12.

5/12 x 36,600 = 15,300 # to be carried by one column.



Two columns act together similar to the "portal" action of a bridge. Height to bottom of cylinder = 45'. Assume fixed ends. Vertical component of wind pressure $= \frac{P\,N}{b} =$

$$\frac{15,300 \times 33.87}{30} = 17,300 \text{ \#.}$$

Horizontal comp. $= \frac{P}{2} = 7,650$ #.

Maximum live load at bottom of cylinder = 271,000 + 17,300 = 288,300 #/col.

Assume columns 36" square. Extra material in tank per column = 1/2 x

$$\frac{30 \times 30 \times 3 \times 150}{12} = 16,850 \text{ \#.}$$

Weight of column below cylinder = 3 x 3 x 45 x 150 = 60,800 #

Total load at bottom of columns = 365,950 #

Compressive stress $= \frac{365,950}{36 \times 36} = 282$ #/sq. in.

Bending moment due to horizontal component of wind pressure

7650 x 22.5 x 12 = 2,060,000 in #

$$S = \frac{Mc}{I} = \frac{2,060,000 \times 6}{36 \times 36 \times 36} = 266 \text{ \#/sq. in.}$$

Combined stress = 266 + 282 = 548 #/sq. in.

Steel ratio $= \frac{548}{450 \times 1.14} = 1.07$ % (See Turneaure and Maurer "Principles of Reinforced Concrete Construction" - page 128)

Steel required = 36 x 36 x .0107 = 13.85 sq. in.

Use 12 - 1 1/4" round rods.

ANCHORAGE FOR COLUMNS

Weight of roof (without snow load)	=	40,000 #
Weight of cylinder walls	=	216,000 #
Weight of Hemisphere	=	110,000 #
		366,000 #

Weight on each column	=	45,750 #
Weight of column	=	77,650 #
		123,400

Upward reaction of column due to wind = 15,300 #

No anchorage necessary.

FOUNDATION

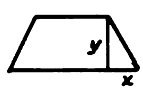
Diameter of column centers = 28'

Spacing of column = $\frac{\pi \times 28}{8} = 11'$

Assume that top is an annular ring 42" wide.

Then inside diameter at top = 24' - 6"

Then outside diameter at top = 31' - 6"

Consider 

cross section of unit width.

$$M = 1/2\ W\ X^2 = \frac{S\ I}{C}$$

$$1/2\ W\ X^2 = \frac{S\ y^2}{6}$$

$$X = y\sqrt{\frac{S}{3\ W}}$$

Assume Modulus of Rupture = 200 #/sq. in.

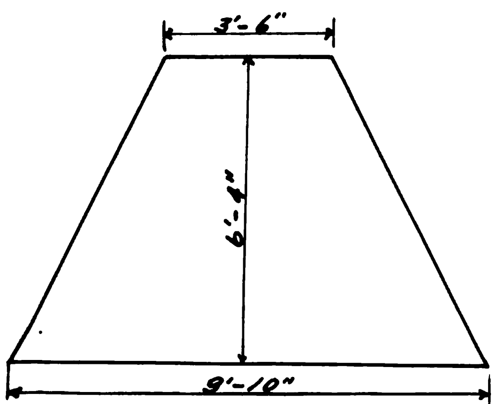
Factor of safety = 10. Then S = 20 #/sq. in.

Assume bearing power of soil = 2 tons/sq. ft.

$W = \frac{4000}{144} = 27.8$

$X = y \sqrt{\frac{20}{3 \times 27.8}} = .5y$ Batter ratio = 1/2

Assume y = 76"



Weight per ft. of length =

$\frac{42 \times 76 + 38 \times 76}{144} \times 150 = 6340$ #

Column pressure per ft. of length =

$\frac{365,950}{11} = 33200$#

Total load per ft. of length =

39,540 #.

Bearing pressure $= \frac{39540 \times 12}{118} =$

4010 #/sq. ft. O. K.

Then inside diameter of base = 18' - 2"

Then outside diameter of base = 37' - 10

SPECIFICATIONS FOR A REINFORCED CONCRETE WATER TANK

Extent of Contract. These specifications include the furnishing of all material and the completion of all work necessary for the construction of a water tank as specified in these specifications, and as shown on the drawings for said tank, which are hereby made a part hereof.

General Description. The tank shall consist of a cylindrical wall, conical roof, and hemisphere bottom, with various appurtenances thereto, supported by columns on a concrete foundation as shown in the drawings for the said tank.

Foundation. The excavation will be of such a form, diameter and depth as to allow the foundation shown on the drawings to be constructed. The bottom of the excavation will be brought to a level and thoroughly rammed and consolidated to the satisfaction of the engineer or inspector.

The foundation shall be of concrete as shown on the plans. Said concrete shall be laid as herein provided.

After the foundation is completed the earth shall be filled in about it, and thoroughly rammed, and after the completion of the superstructure, the surplus earth shall be graded to the satisfaction of the engineer.

Superstructure. The walls, bottom, roof and columns, together with the accessories thereto, shall be built as provided herein and as

shown on the plans.

Concrete. The concrete in the foundation shall be a 1:3:5 mix, made and laid in accordance with the specifications of the American Railway Engineering and Maintenance of Way Association for Portland cement concrete.

Reinforced concrete shall be a thoroughly uniform mixture of cement, sand, stone and water completely enveloping the reinforcing rods.

The volume of sand shall be 5% in excess of the volume of voids in the stone. The volume of the cement (considering 100# = 1 cu. ft.) shall be 25% in excess of the volume of the voids in the mixed sand and stone. The engineer shall determine the voids and proportions.

The volume of water shall be sufficient to give the concrete a fluidity that will cause it to flow and mould itself in the forms without tamping.

The concrete, after mixing, shall be poured and worked into final position in the forms before its initial set is complete, and it shall not thereafter be disturbed. As it is thus placed it shall be thoroughly worked by long, flat, thin bladed tools in a manner that will eliminate all voids and air pockets and produce unbroken mortar faces against all forms and secure perfect contact with every part of all reinforcing rods.

The surface of concrete shall be clean and wet when concrete

is laid thereon. The surface, if hardened shall also be mopped with cement grout immediately in advance of placing fresh concrete. Smooth or finished mortar surfaces shall be avpided where additional concrete is to be placed.

A rapid drying out of concrete shall be prevented by regular, frequent and continued wetting until all danger of arrested setting and hardening is past, as the engineer shall direct. Freezing of concrete before it has finally set shall be prevented.

All concrete broken or displaced in any manner after having set shall be removed from the work.

Materials. The cement shall conform to the specifications of the American Society for Testing Materials. The sand shall be clean, sound and sharp, and it shall be of graded sized grains giving a minimum of voids. The stone shall be clean, sound and durable. The word "stone" includes broken rack and gravel.. The stone shall be of graded sizes giving a minimum of voids. All of it shall be able to pass thru a circular hole having a diameter of 3/4".

Forms. The concrete forms shall be made of metal or of dressed and matched lumber. They shall be accurately made and erected, be water tight, and shall have ample strength and rigidity to prevent bending and warping under load. They shall be erected in such sections and courses as will permit the concrete to be poured and worked as above specified. No device for holding the forms that would leave a hole thru the con-

crete shall be used. Wires passing thru the concrete shall be nipped off beneath the concrete face.

Reinforcement. The concrete shall be reinforced by steel rods of the form, size, number and arrangement shown on the drawings. They shall be wired at intersections with each other, and be maintained in required position as they are buried in the concrete, at which time they shall be free from dirt and scale. Splices in rods shall be lapped 42 diameters. No splices shall be opposite a splice in an adjacent line of rods. There shall not be more than four splices in the circumference of the tank. Unnecessary splices shall be avoided.

Reinforcing rods. The reinforcing rods shall be plain or deformed. Their tensile strength shall be between 60,000 and 90,000#/sq. in. Their elastic limit shall not be less than half their tensile strength. Any rod shall be capable of being bent cold on a radius of three diameters thru 180° without sign of fracture.

Waterproofing. A dense, even mixture of concrete as herein specified for reinforced concrete shall be the primary expedient to secure water tight concrete. This may be supplemented by mixing with the cement some form of waterproofing compound of proved efficiency. Where the concrete can be worked before it has set, the surface shall be thoroughly troweled until a dense mortar face is secured. Concrete surfaces already set may be plastered by rich cement mortar, but surfaces so treated shall first be cleaned and roughened by steel brushes

or their equivalent, and the plastering shall be applied on a fresh coat of cement grout mopped on the surface.

In addition, if necessary, separate and alternate washes of soap and alum in the order named shall be applied to the dried and hardened concrete surface. The number of washes should be not less than two of each, with a 24 hour interval between each. The proportions should be approximately 3/4 lb. of soap and 1/8 lb. of alum per gallon of water. These proportions may be varied if better results are thereby secured. The soap wash shall be applied boiling hot, without causing frothing. The alum wash should have a temperature between 60 and 80° F.

In all washing the concrete surface treated shall be dry and clean, and the temperature should be above the freezing point.

<u>Testing.</u> After completion, the tank shall be filled with water, and must show no leaks after standing one week.

APPROVED

F. E. Turneaure